

Experiments with fast radioactive beams at GSI

Recent developments and results



Thomas Aumann



TECHNISCHE
UNIVERSITÄT
DARMSTADT

HIC for FAIR
Helmholtz International Center



NAVI
Nuclear Astrophysics Virtual Institute



Bundesministerium
für Bildung
und Forschung

August 16th 2012

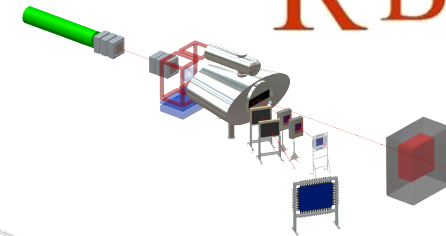
Nuclear Structure 2012

Argonne National Laboratory

FAIR -> NuSTAR -> R3B -> Dipole response
Quasi-free Scattering

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FAIR – Facility for Antiproton and Ion Research

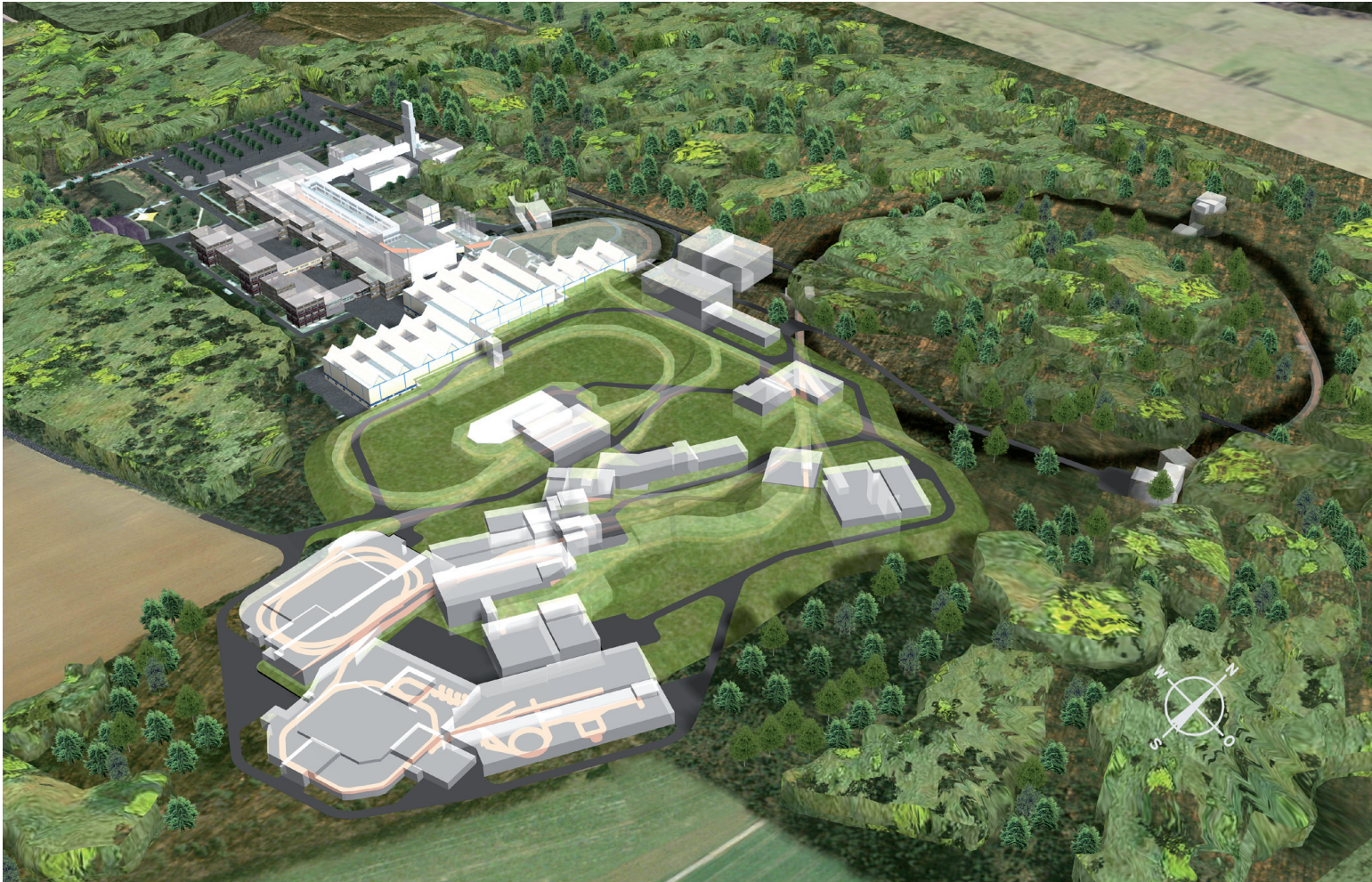


Figure 1.1: Artists view of FAIR. The synchrotrons on the right will be located 10 to 13 m underground and will not be visible in reality. Most of the roofs will be vegetated and thus most of the facility will be hidden from view.

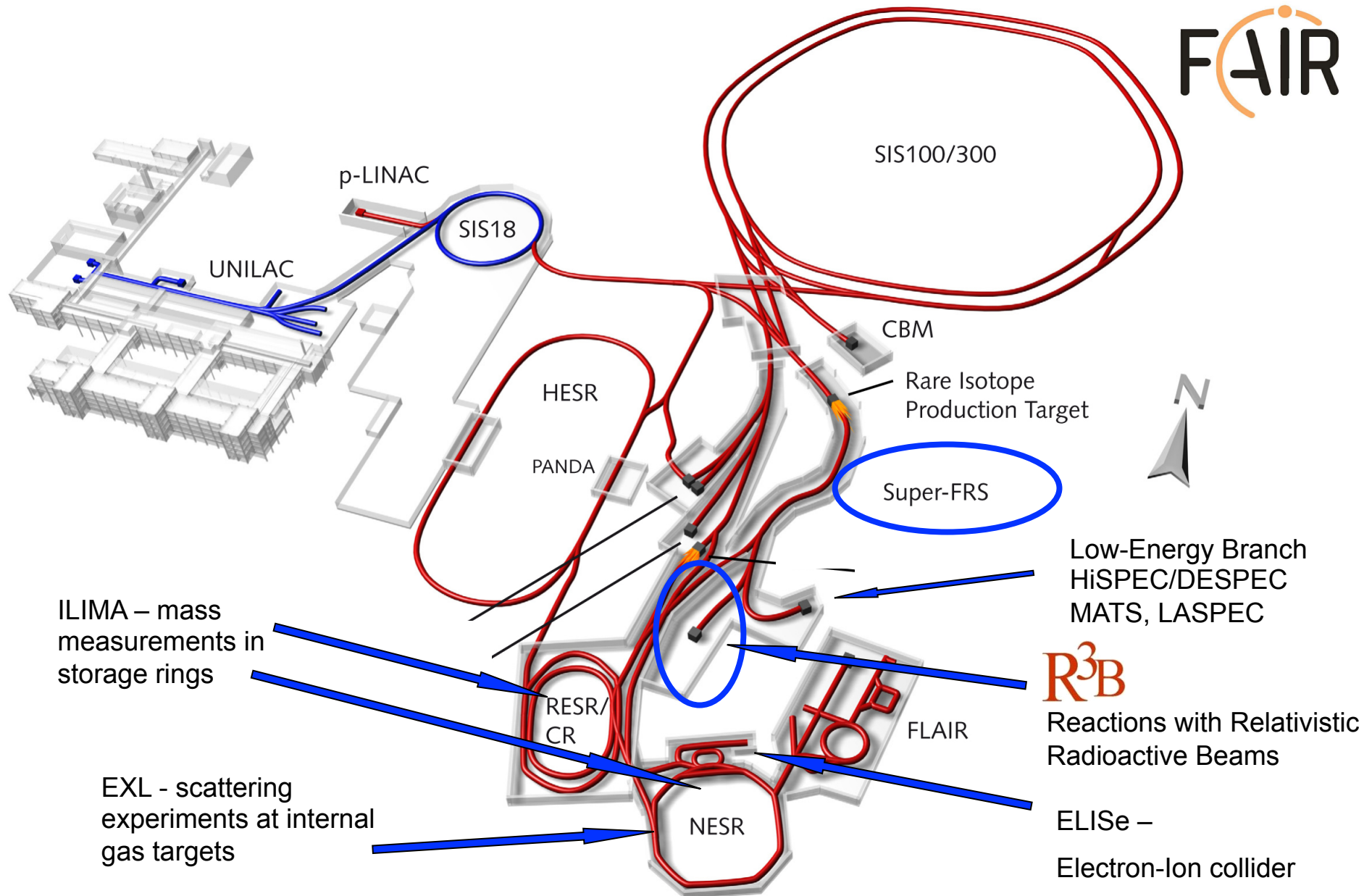
FAIR

02.07.2012 | Greatest Grant Notification of BMBF History for Particle Accelerator FAIR

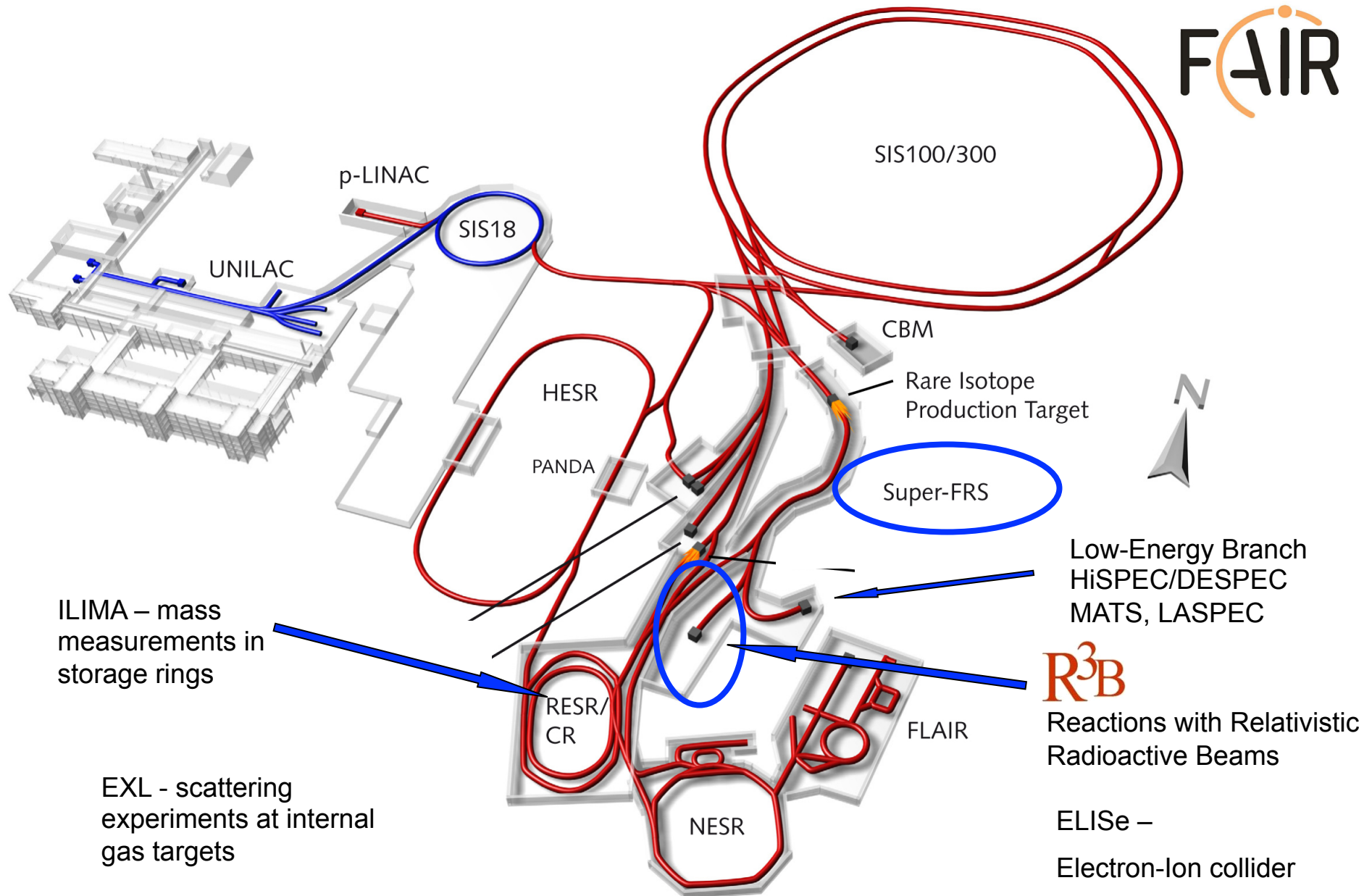


Parliamentary State Secretary Helge Braun presented FAIR today with the greatest grant notification for a research project in the history of the Federal Ministry of Education and Research (BMBF) **of 526 million Euro** and thus **gave green light for the construction of the facility.**

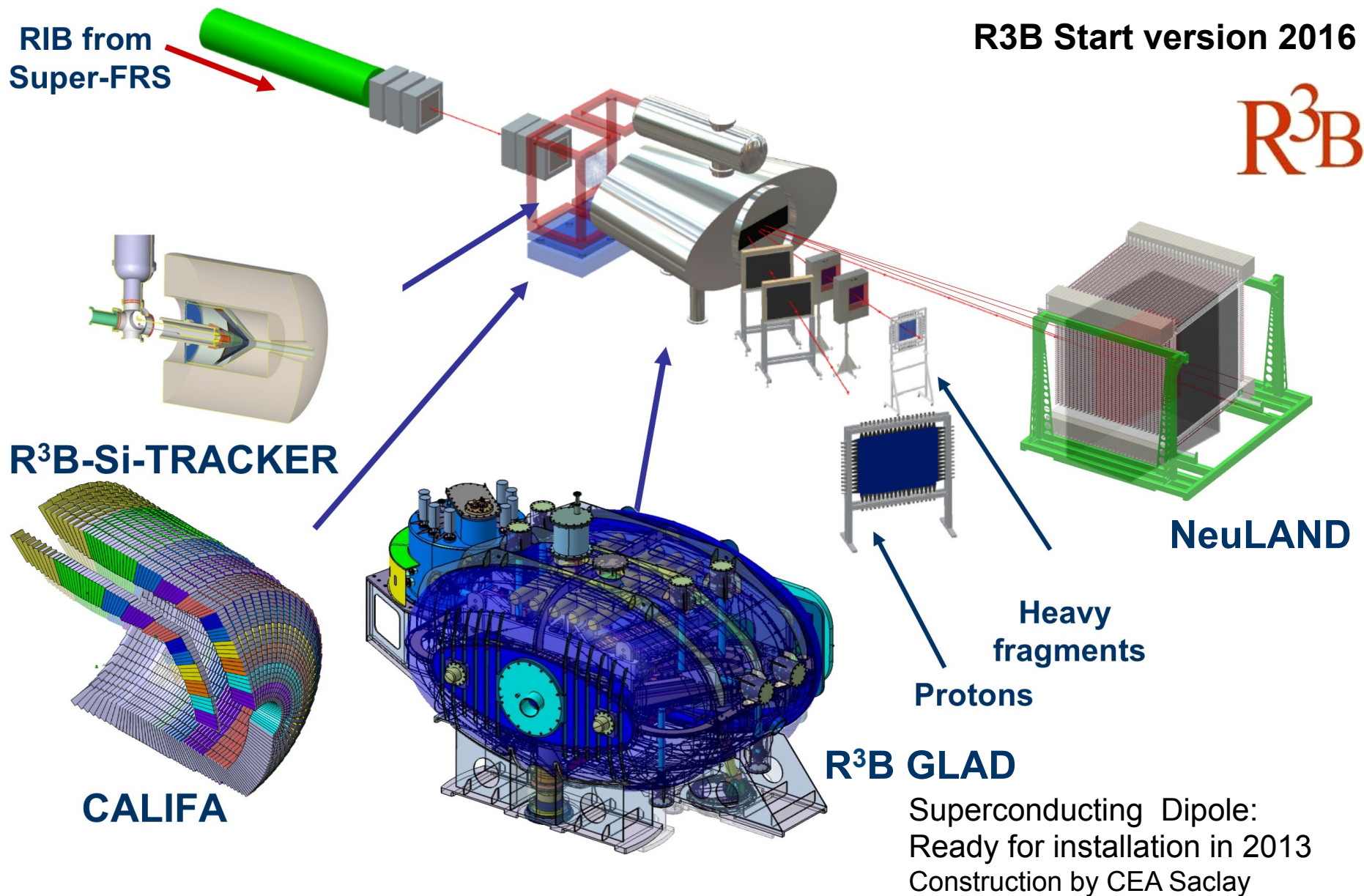
High-energy radioactive beams at FAIR



High-energy radioactive beams at FAIR



Reactions with Relativistic Radioactive Beams

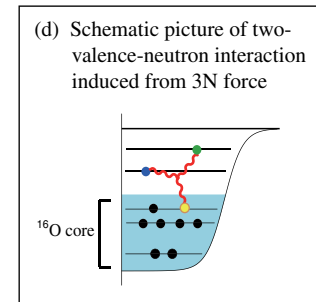
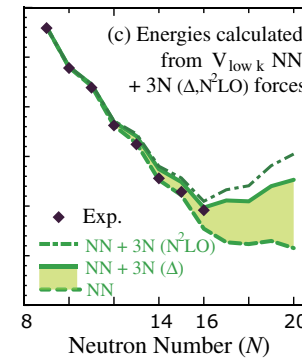
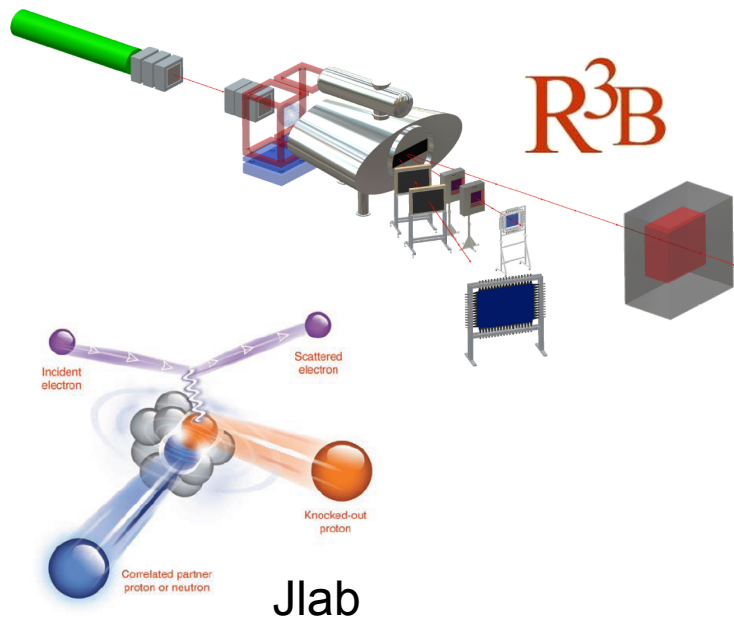


Quasi-free scattering in inverse kinematics with high-energy radioactive beams

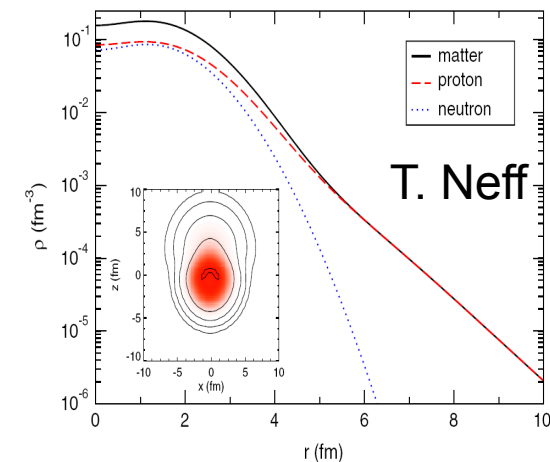
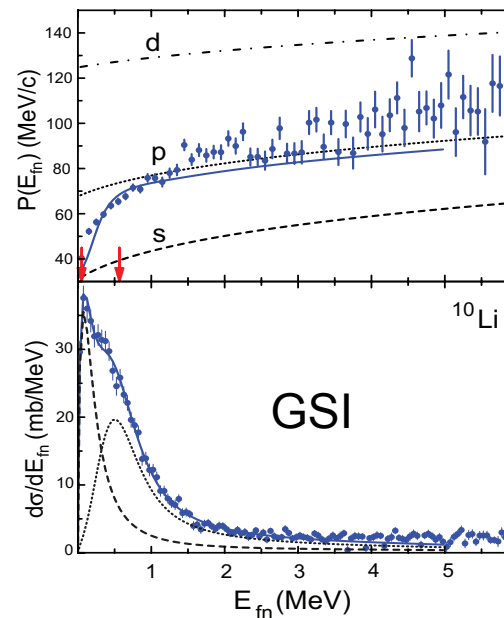
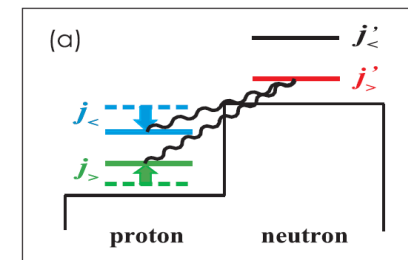
Quasi-free knockout reactions

(p,2p), (p,pn), (p,2p,n), (p,pd), (p,p α)

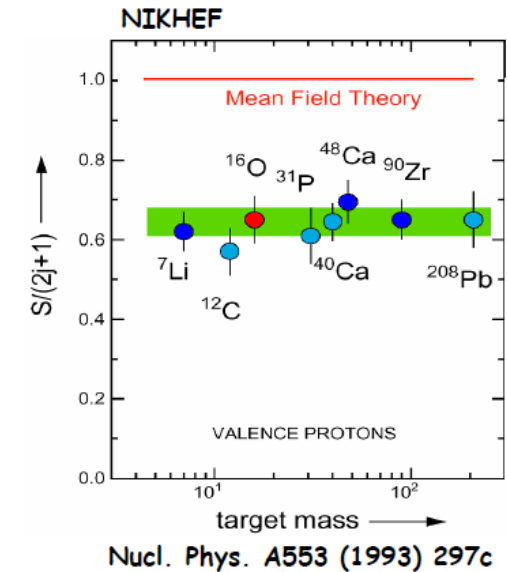
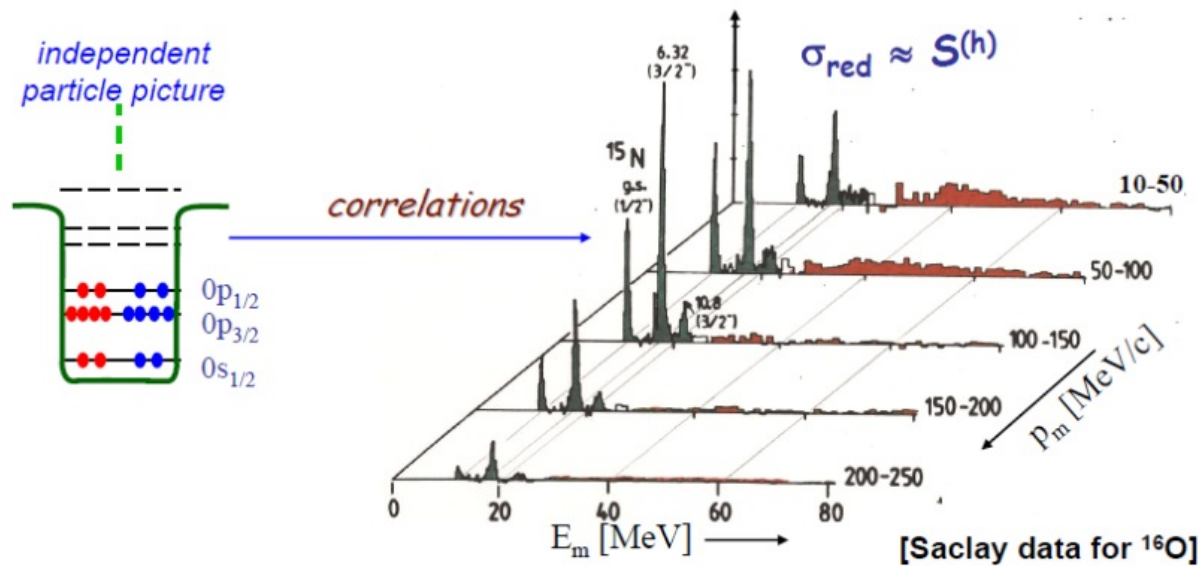
- Evolution of Shell structure
- Nucleon-Nucleon Correlations
(short-range, tensor, ...)
- Cluster structure
- States beyond the neutron dripline



Otsuka et al.



Single-particle structure and correlations



Deviation from the independent-particle picture:

Correlations: Configuration mixing,

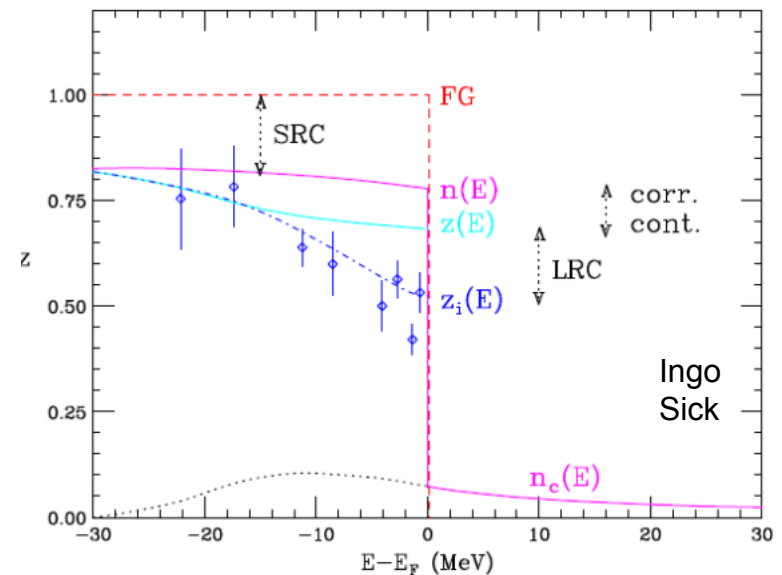
Coupling to collective phonons

Short-range and tensor correlations

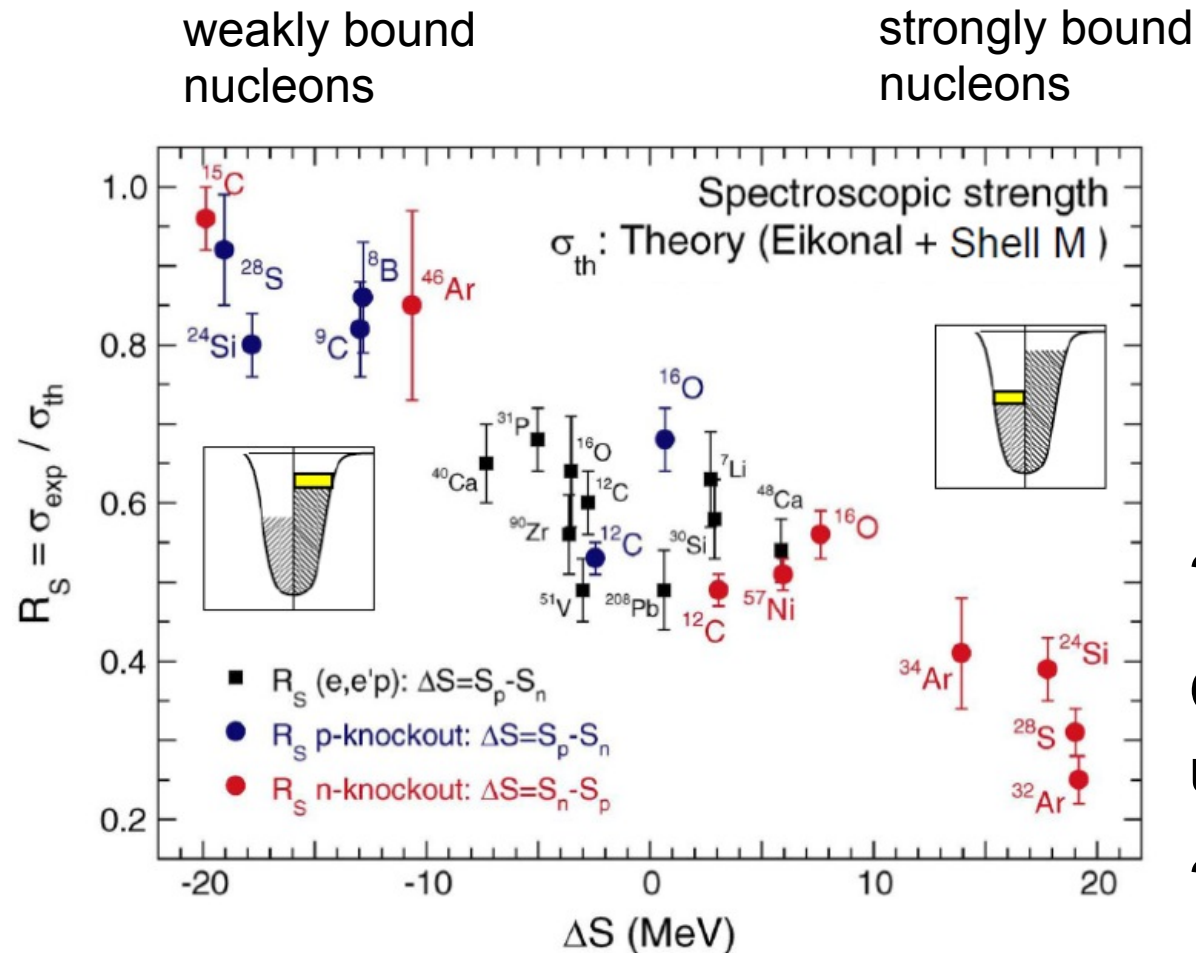
→ high momenta

→ reduced single-particle strength

(occupations, spectroscopic factors)



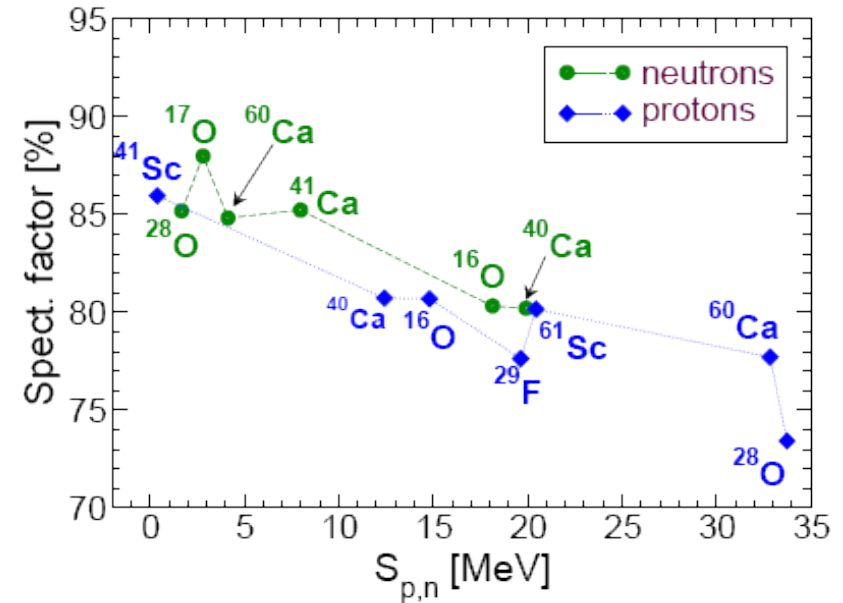
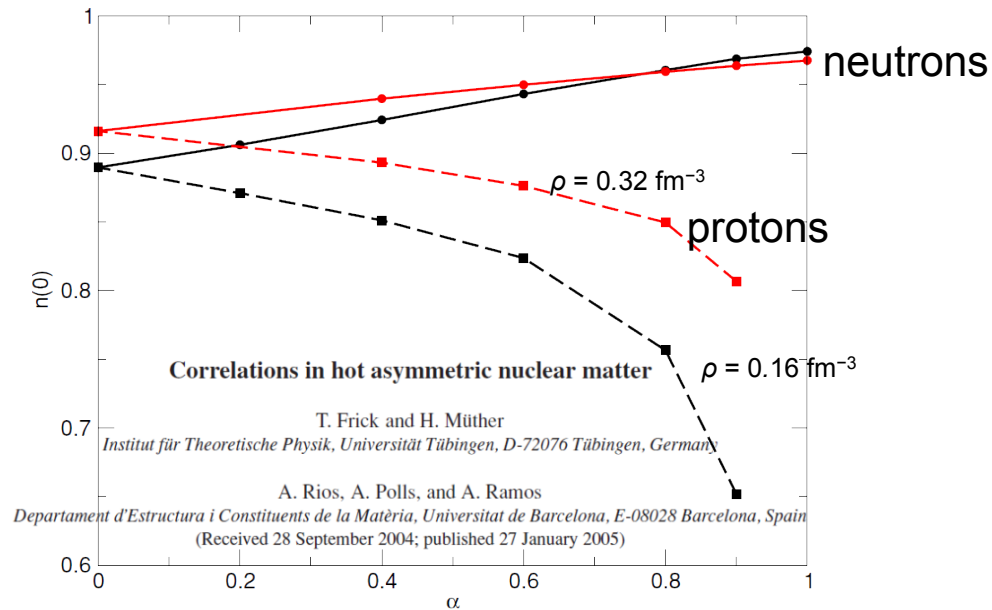
Single-particle cross sections Quenching for neutron-proton asymmetric nuclei



?
Origin
unclear
?

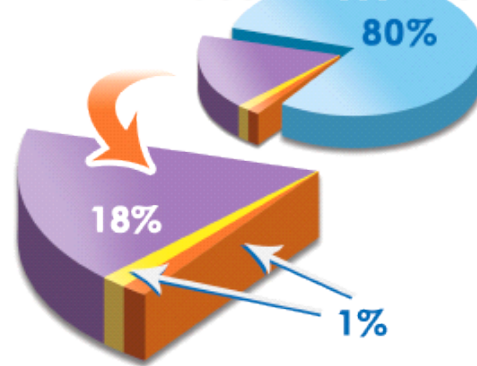
Figure from Alexandra Gade, Phys. Rev. C 77, 044306 (2008)

Correlations in asymmetric nuclei and nuclear matter



Probing Cold Dense Nuclear Matter

Subedi et al. 13 JUNE 2008 VOL 320 SCIENCE

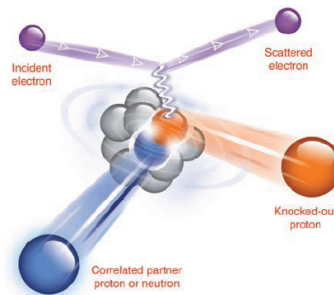


Single nucleons

n-p

n-n

p-p



Electron-induced
knockout (JLab)

SPECTROSCOPIC FACTORS IN ^{16}O AND NUCLEON ASYMMETRY

arXiv:0901.1920v1 [nucl-th] 14 Jan 2009

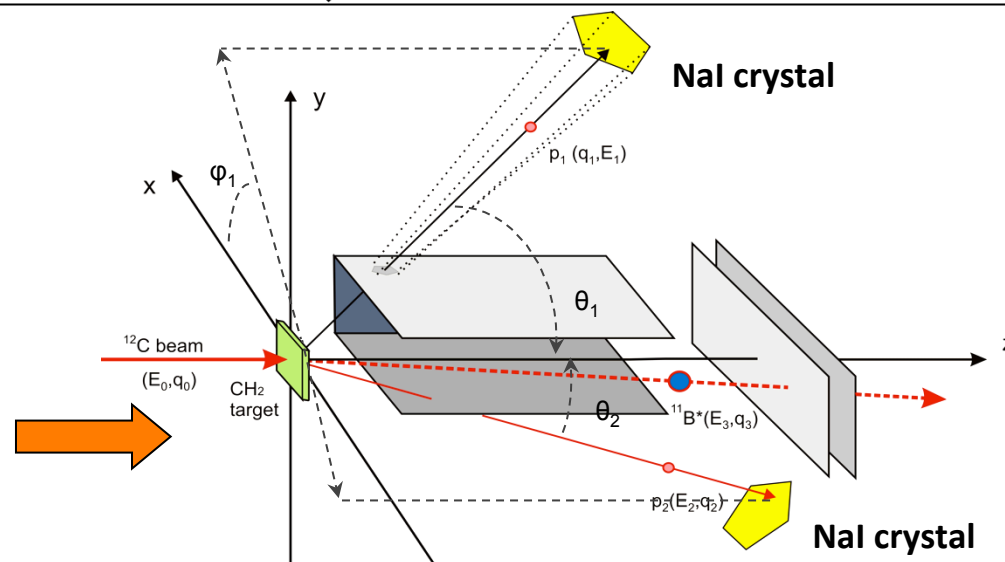
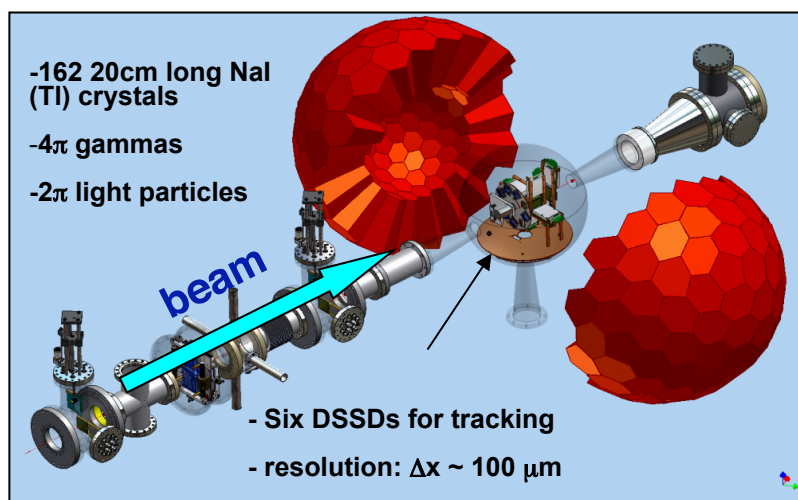
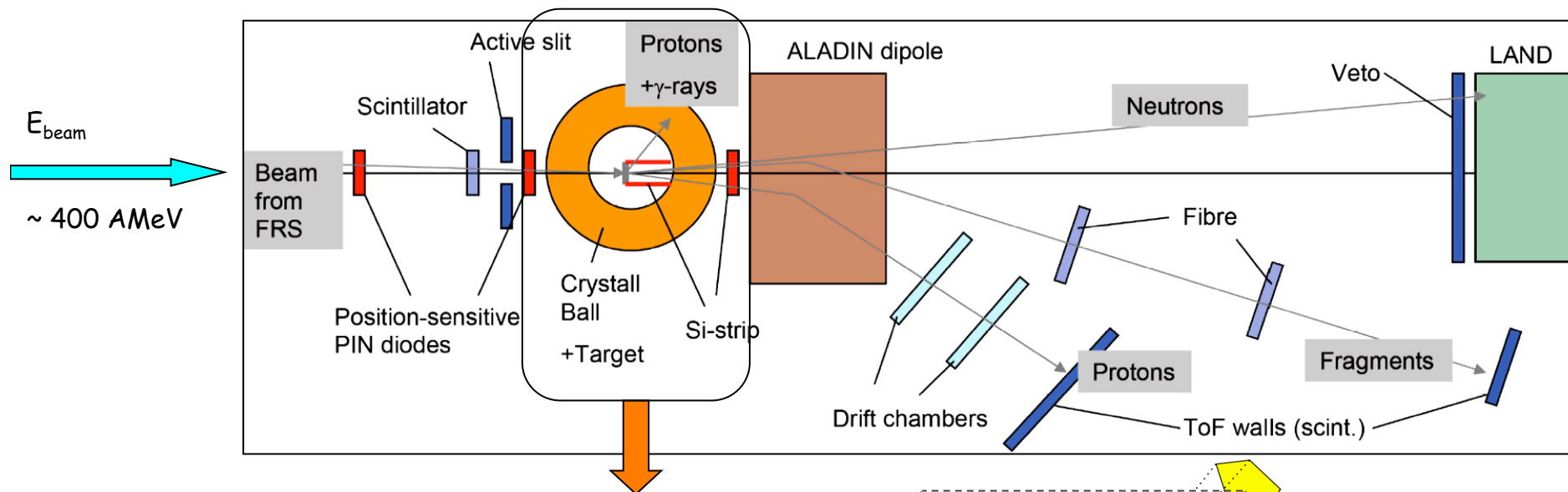
C. Barbieri

Theoretical Nuclear Physics Laboratory, RIKEN Nishina Center, 2-1 Hirosawa, Wako, Saitama
351-0198 Japan

W. H. Dickhoff

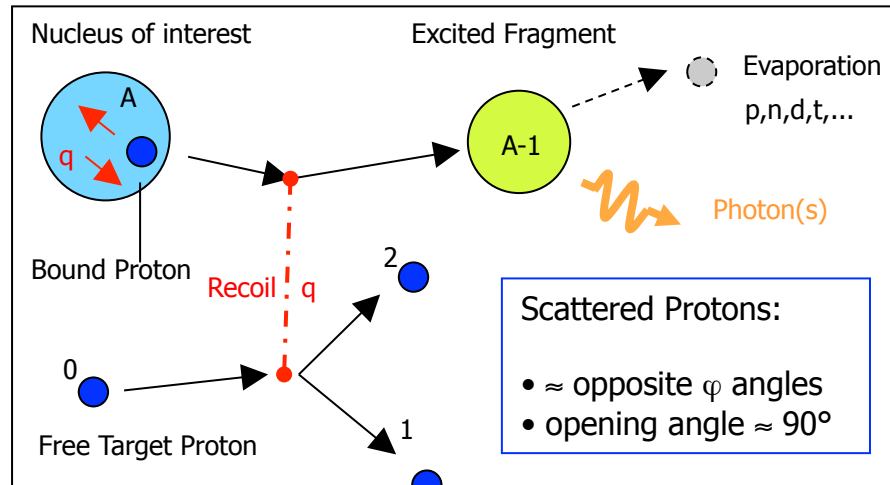
Department of Physics, Washington University, St. Louis, Missouri 63130, USA

Experimental setup: LAND/R3B@GSI



Quasi-free scattering with exotic nuclei: $^{17}\text{Ne}(p,2p)^{15}\text{O}+p$

The two-proton Halo (?) nucleus ^{17}Ne



Internal Momentum

Separation Energy

$$q = -p_{A-1} = p_1 + p_2 - p_0$$

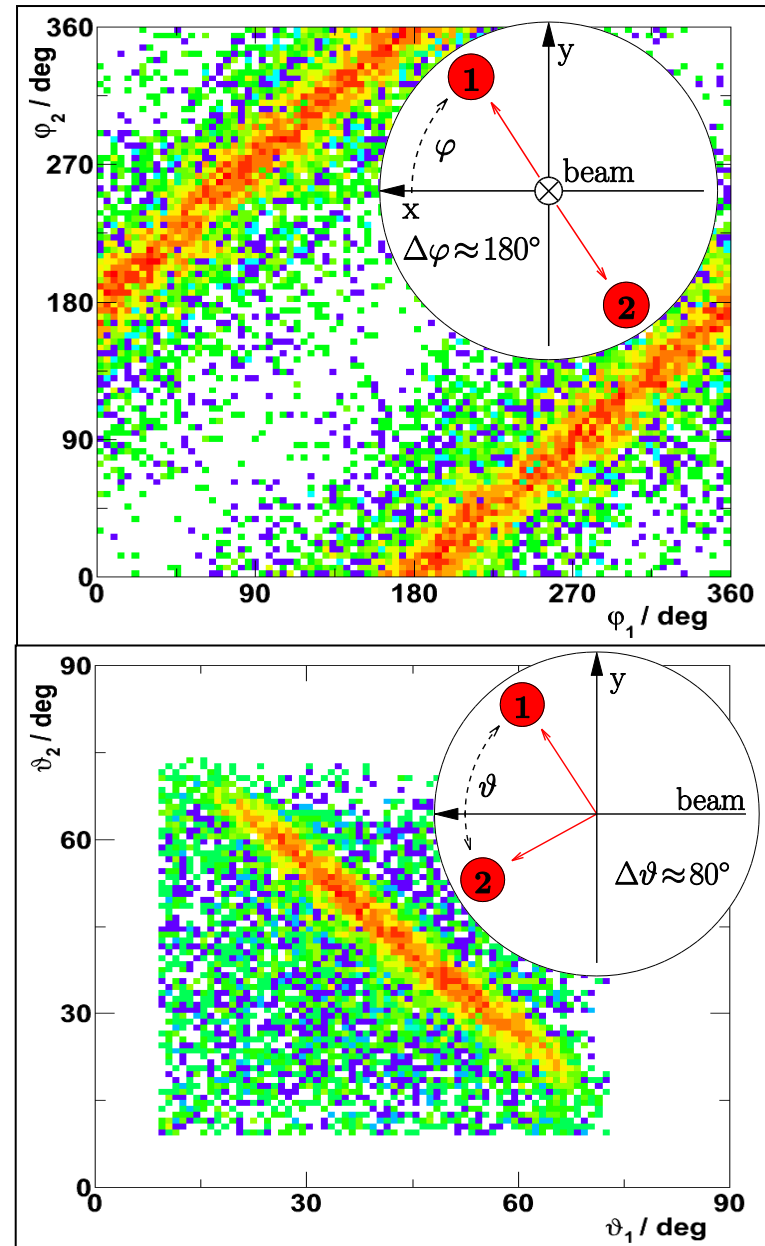
$$E_S = T_1 + T_2 + T_{A-1} - T_0$$

Pilot experiments with ^{12}C , ^{17}Ne and Ni isotopes already performed at the LAND-R3B setup are under analysis ...

Angular Correlations measured with Si-strip detectors for $^{17}\text{Ne}(p,2p)^{15}\text{O}+p$

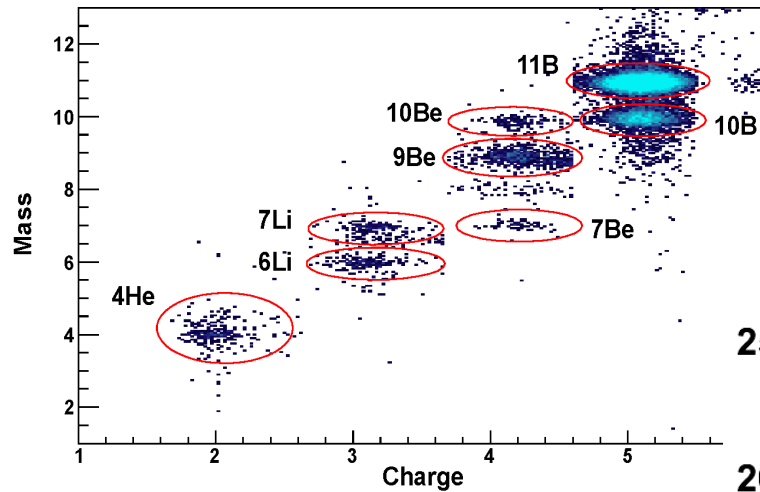
$\Delta\theta \sim 180^\circ$, $\Delta\phi \sim 83^\circ$ (sim. as for free pp scattering)

^{17}Ne , Felix Wamers, PhD thesis



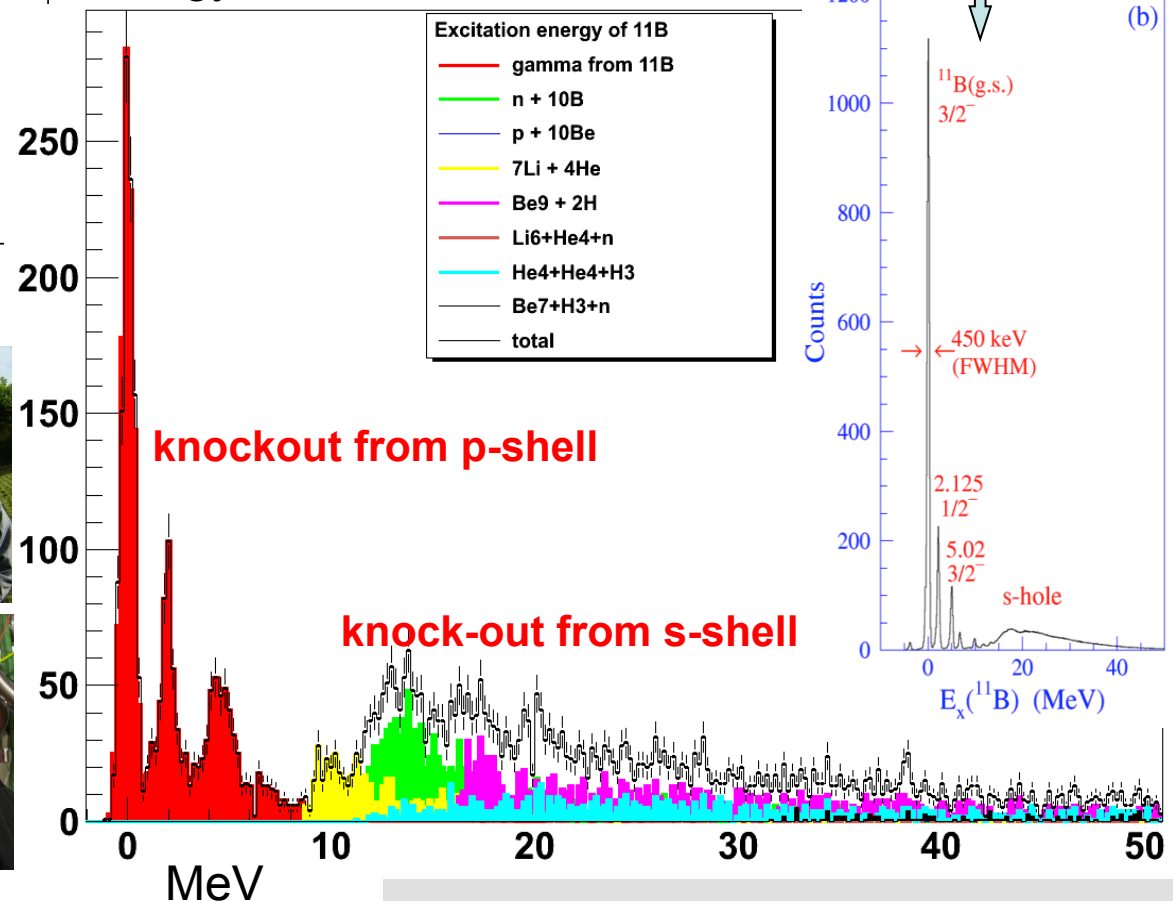
Benchmark experiment: $^{12}\text{C}(p,2p)$ in inverse kinematics

Fragments produced in $^{12}\text{C}(p,2p)$



M. Yosoi, PhD Thesis, 2003,
Kyoto University

Reconstructed excitation
energy of ^{11}B



Jon Taylor, PhD thesis,

Univ. of Liverpool

Valeri Panin, PhD thesis,

TU Darmstadt

R3B preliminary data 2011, unpublished

Relative population of p-hole states $^{12}\text{C}(p,2p)^{11}\text{B}$

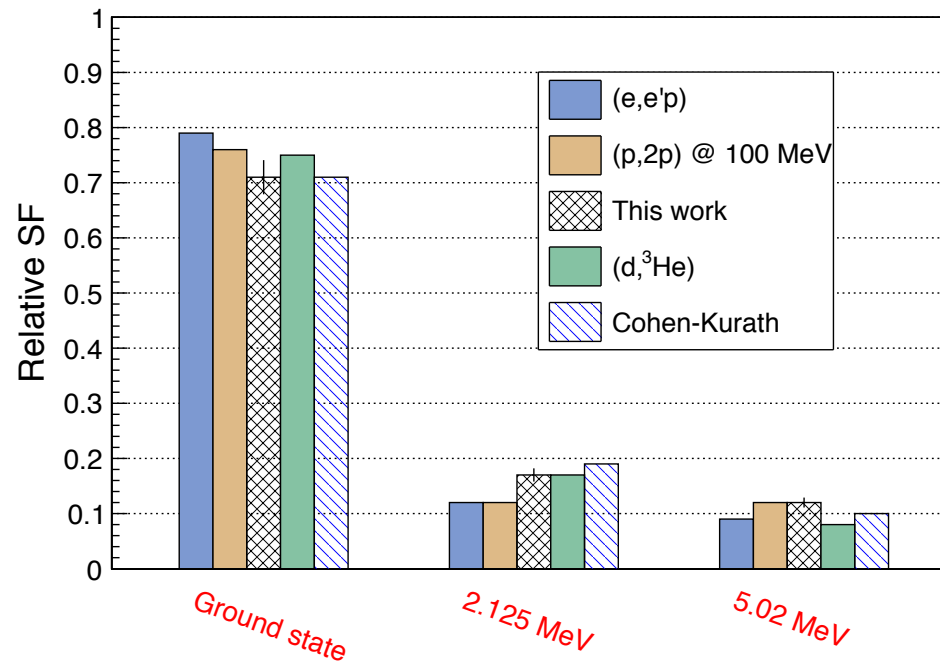
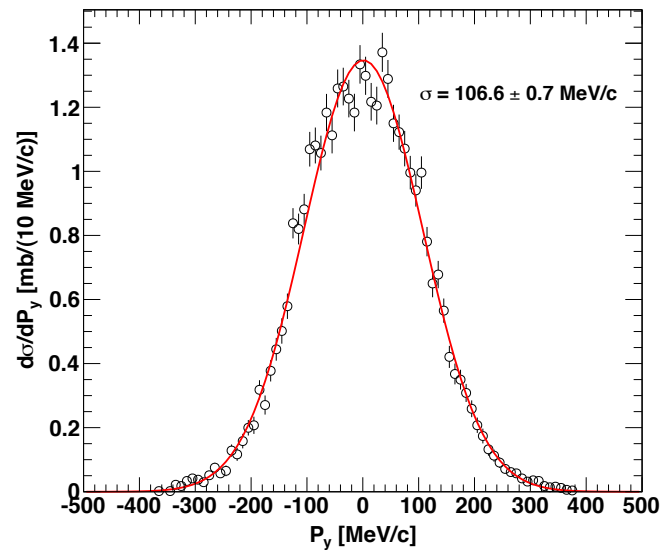


Figure 5.1: The relative populations of the three p-hole states in ^{11}B are compared with the relative spectroscopic factors obtained from (e,e'p), (p,2p) and (d, ^3He) experiments. A comparison with the theoretical Cohen-Kurath calculations [7] is shown as well. The sum of the relative values of all three states is unity in each case.

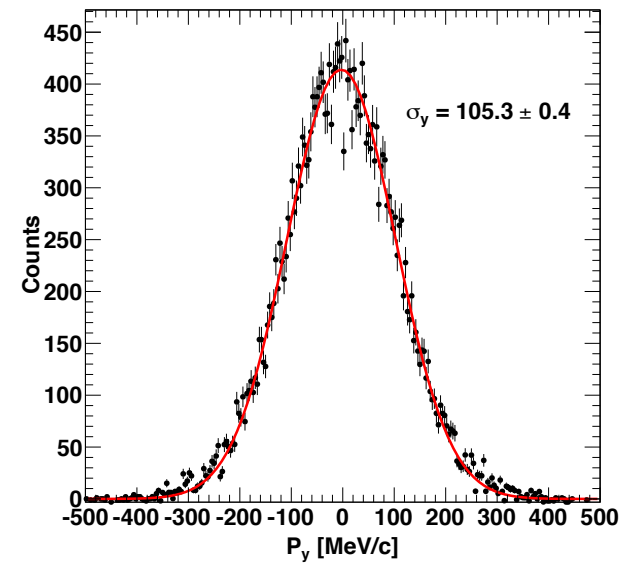
Momentum Distributions

$^{12}\text{C}(p,2p)^{11}\text{B}$

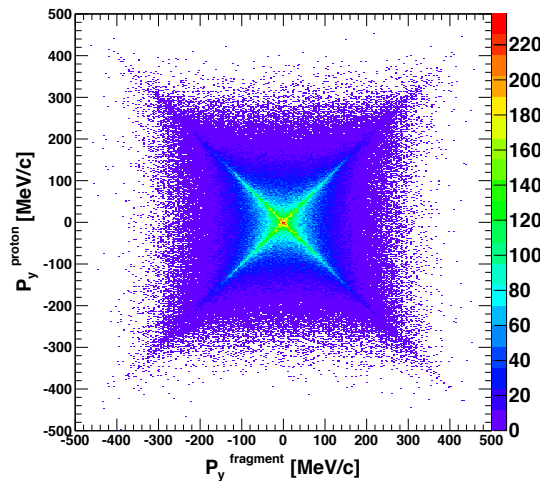
Fragment recoil momentum



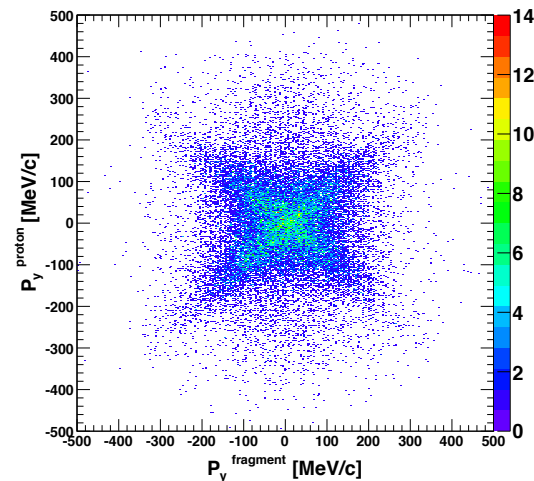
Reconstructed from proton measurement



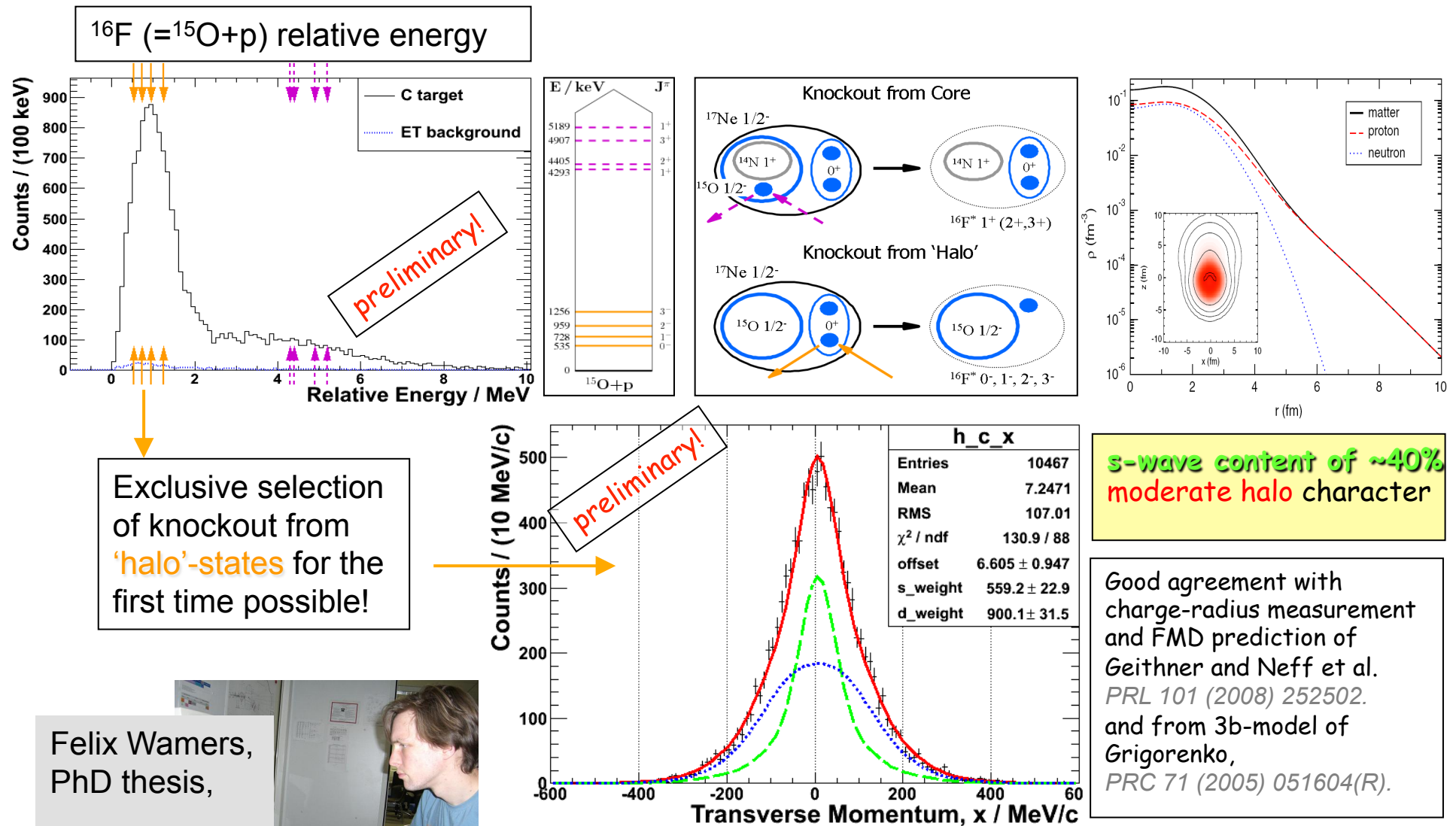
Simulation



Measurement















Selective one-proton knockout from core- and 'Halo'- states in ^{17}Ne



Felix Wamers,
PhD thesis,
TU Darmstadt

R3B preliminary data 2011, unpublished

The Collaboration

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 *V. Volkov*⁶, *A. Wagner*², *F. Wamers*⁶, *J. Weick*², *M. Weigand*⁴, *C. Wheldon*⁵, *G. Wilson*⁹, *C. Wimmer*⁴,
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Japan; ¹⁹University of Notre Dame, United States; ²⁰University of Edinburgh, United Kingdom

Summary

- Dipole response of n-rich nuclei – Pygmy Resonance
 - Low-lying dipole strength observed in n-rich nuclei, ‘proton-Pygmy’ in ^{32}Ar
 - first attempt to extract n-skin thickness and density dependence of symmetry energy
 - many open questions – next-generation experimental program planned at GSI, RIKEN, SDALINAC, HIγS, Osaka, ...
 - systematics, strength and position as a function of N-Z (and mass)
 - isospin character (isoscalar dipole)
 - decay properties
 - relation to nuclear-matter properties
 - relation to observed low-lying strength for stable nuclei
 - extraction of quadrupole strength
- Quasi-free nucleon knockout in inverse kinematics
 - QFS successfully applied in inverse kinematics
 - Rich physics program: N-N correlations, shell structure, cluster structure, unbound nuclei
- R3B development towards FAIR
 - Technical Design Report for neutron detector NeuLAND and calorimeter CALIFA ready
 - R3B hall ready for installation in 2017, start of R3B @ FAIR with Super FRS in 2018